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NASA FIRE DETECTION STUDY

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I. Introduction/Background

The National Aeronautics and Space Administration, together with the National Institute of Standards and Technology are in the third year of a five year project designed to set guidelines for fire protection in high bay facilities. There is a special need to address fire protection issues for high ceiling height (high bay) spaces. NASA has numerous high bay spaces that are used to perform a variety of functions. Many of these functions are critical to meeting the goals of the NASA strategic plan. Examples of high bay spaces at NASA include those used for clean rooms, shuttle simulators, assembly/storage, vacuum and vibration chambers, vehicle assembly, and/or testing facilities with payloads. These spaces represent some of the most difficult fire protection challenges in that detection of a fire in a large space may be delayed due to the distance smoke and products of combustion must travel to reach the detector, the large amount of ambient air for smoke dilution, the high dollar value of these spaces, and the low damage threshold of a clean room. Some of these spaces also involve forced air flow.

Accurate detector predictions are important in these large spaces, as timely detection of a fire is more difficult due to the distance heat and products of combustion must travel to reach sprinklers and detectors. Since fires frequently grow at an exponential rate, an increased time to detection results in larger fires to be suppressed by, e.g., an automatic sprinkler system. Even a modest uncertainty in the prediction of the activation time may lead to a large uncertainty in the fire size used to predict the hazard, a central element of many fire protection analyses. The issue of prediction of activation time was addressed during the first year of this project. Experimental measurements taken during a fire in a 30 m (100 ft) high aircraft hangar were compared to the predictions of the fire models DETACT-QS, LAVENT, and FPETOOL, and also to the predictions of a computational fluid dynamics (CFD) model, HARWELL FLOW3D. The CFD calculations, using modified k-ε parameters, provided the best agreement with experimental measurements. The CFD model was then used to model the hot gas movement in a NASA Goddard Space Flight Center high bay clean room. Information regarding detector placement and sensitivity was obtained as a result of this effort. A final report, " The Use of Computer Models to Predict Temperature and Smoke Movement in High Bay Spaces", NISTIR 5304, Dec 1993, was delivered to NASA. This report fully documents the modeling procedure, inputs and results.

In the second year of this study, NASA locations were surveyed to determine the number and size of existing high bay facilities, their usage, and criticality to the NASA mission. The survey identified special hazards, target fire sizes, existing detection and suppression systems, and the presence of forced air flows. Site visits were conducted to view high bay spaces at selected locations. Results of the survey were correlated to produce a matrix of NASA high bay spaces.

CFD modeling was used during the third year of the study to determine the appropriateness of available detection and suppression systems for each type of NASA space. Based on the modeling results, guidelines were drawn up to indicate which detection and suppression strategies would be successful as a function of fire size, forced ventilation, and ceiling height. The activation of a suppression system was modeled, not the capability of the system to extinguish the fire.

II. Survey Results

A survey form was developed that identified the occupancy/use of the space, the primary concern with fire protection in the space, and any information on any special geometry, temperature, or activity concerns in this space.

Data were also collected to be used in the modeling of a space. Variables such as the ceiling height(s), whether or not the ceiling is flat, the depth and thickness of various beams below the ceiling, and the presence of ceiling vents and/or draft curtains affecting the smoke flow in the space and thus the detection of a fire. The rate of air flow, and the uniformity of the flow from floor to ceiling were used to calculate the effect of forced air flow on the plume.

Information on the type and amount of any materials contained in this space was collected so that special consideration could be given to, e.g., explosive or radioactive materials. An estimate of the maximum acceptable fire size, defined as the largest fire size tolerable in the space considering the dollar value loss potential and criticality to the NASA mission was collected so that suitable detection strategies could be determined. On the survey form, NASA engineers were asked to select a maximum acceptable fire size from one of three choices. Choices were a 50 kW fire (ex. a wastebasket fire), up to a 1 MW fire (ex. a 1.5 m (5 ft.) floor area of 4.6 m (15 ft.) high storage of ordinary combustibles), or a greater than 1 MW fire (ex. > 0.8 m diameter JP-4 fire).

Information on automatic smoke detectors (e.g., photoelectric, ionization, beam, and/or continuous sampling), heat detectors (e.g. fixed temperature, rate of rise, or combination), and flame detection (infrared or ultraviolet) is used to determine the adequacy of existing fire protection in the space. Information on whether the space contains an automatic extinguishing system, and what type, was also obtained for each space.

A plan view including the length and width of the space, the approximate location of ceiling vents and/or draft curtains, and the approximate location of ceiling detectors was drawn for each space. Also drawn for each space was an elevation which includes the ceiling height(s), the geometrical configuration of the ceiling, the direction of forced air flow, and the approximate location of wall detectors. This information was also needed for modelling of the space.

III. Analysis

Data from the surveys were collected and analyzed. A total of 70 high bay spaces were identified at 13 NASA locations. These are all NASA owned buildings and do not include buildings which NASA contractors own.

Most locations reporting radiation detectors had a combination UV/IR detector. The term thermal/smoke was used to refer to smoke detectors, heat detectors, and automatic fire sprinklers.

The high bay spaces were grouped by height into three categories: 18 to 26 m (60 to 85 ft), 27 to 37 m (90 to 120 ft), and over 37 m (120 ft). Most of the spaces in the inventory had flat ceilings.

There were a total of 36 spaces (51%) between 18 and 26 m (60 and 85 ft) high; 25% of these had no detectors, 39% had thermal/smoke detectors with no forced air flow, 22% had thermal/smoke detectors with forced air flow, and 14% had radiation detectors.

There were a total of 25 spaces (36%) between 27 and 37 m (90 and 120 ft) high; 32 % of these spaces had no detectors, 32% had thermal/smoke detectors with no forced air flow, 4% had thermal/smoke with forced air flow, and 32% had radiation detectors.

There were a total of 9 spaces (13%) with ceiling heights greater than 37 m (120 ft); 45 % of these spaces had no detectors, 22% had thermal/smoke detectors with forced air flow, and 33% had radiation detectors.

Thirty nine percent of the structures had a maximum acceptable fire size of less than 50 kW. Some interesting observations were that 7 structures having a maximum acceptable fire size of less than 50 kW had no detectors. Only 6 structures (9%) reported a maximum acceptable fire size of greater than 1 MW. Nine structures (13%) had forced air flow, 89% of which had ceiling heights between 18 and 27 m (60 and 85 ft).

IV. Site Selection for Modeling

From the survey, it was decided that the bulk of the mission critical spaces were located at Kennedy Space Center. These spaces presented some of the most demanding fire detection problems due to the presence of hypergols and the associated hazards posed by the spill of these fuels. Based on the importance of the high bay structures to the NASA mission and the potential for useful information to be gained from the modeling, it was decided to run computer fire model simulations for an orbiter processing facility, and a payload processing facility. The loss of either of these facilities due to a fire would have a significant impact on the NASA shuttle schedule. Both of these structures are clean rooms with approximately 30 m (100 ft) high ceilings.

A third high bay to be modelled is a 26 m (95 ft) high hangar at Langley Research Center. This space has a sloping ceiling and includes draft curtains. While the maximum ceiling height is 26 m, the sloping ceiling provides locations in the building where the ceiling height is as low as 18 m (60 ft).

V. Computer Modeling

Several fire scenarios were chosen to be analyzed for each high bay category. For clean rooms or in situations where hypergolic fuels were present, survey results suggested that fires be detected by the time their heat release rate had reached 50 kW. In less hazardous situations, heat release rates of 1 MW or more might be tolerated before detection. This talk focuses on the detection of t-squared fires reaching 50 kW, 1 MW, and 4 MW. It is assumed that a time of 100 s would be required for the fires to reach their maximum size. In addition, a rapidly growing fire to 50 MW is analyzed. The 50 MW fire would simulate a significant spill of hypergolic fuels from an orbiter payload.

The response of smoke, fusible link, heat, UV/IR, and obscuration detectors were modelled using algorithms developed for the CFD fire model using the fire scenarios given above. In the first two categories where ceiling heights range from 18 m to 37 m (60 ft to 120 ft), the modelling was done for both forced and unforced air flows. The forced air flows were chosen to represent specific flows observed in NASA clean rooms. These flows typically originate from ceiling mounted supplies and exit at wall mounted returns near the floor. There were no clean rooms in the NASA inventory for the third category where ceiling heights exceeded 37 m (120 ft) and so forced air flows were not included in the analysis for this category.

This presentation will focus on the results of the modelling of heat, fusible links, smoke and obscuration detectors in high bay spaces. Expected ceiling temperatures and activation times are presented in the analysis of fusible link activation and heat detection at the ceiling of these spaces for the fire scenarios under consideration. An estimate of activation time for smoke and obscuration detectors is presented based on the predictions of the smoke movement models used in the calculations. In particular, the effect on smoke movement of forced air flow from ceiling mounted supplies in the orbiter processing facility and the payload processing facility will be discussed. In each of these facilities, workstands or the presence of the orbiter coupled with forced air flow complicate smoke movement and make detection strategies more challenging.

Discussion

James Quintiere: To come back to the point of scale models, it would seem that these facets of this problem could ideally be complimented by using the scale models. Have you thought of that?

William Davis: Well, you always have to have scale models. The analysis that will be done this year at NIST will probably dictate the experimental areas that need to be looked at. But certainly, scale models with their ability to be run many times are sometimes very preferable to a large-scale experiment which you can only conduct once or twice or three times with not as much control.

James Quintiere: I think the scale model could serve to validate your computer results better than the full-scale tests.

William Davis: Having the opportunity to use these full-scale tests, which weren't run for this particular project, is very useful. We need small-scale tests, and we certainly can't afford to buy a million dollars of full-scale tests.